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16. ABSTRACT

Observations of mean pollutant concentration profiles downwind of a block-sized model building are reported. These data are part of a more comprehensive field model study of building wake effects conducted in the U.S. Environmental Protection Agency's Fluid Modeling Facility. The study includes point measurements of pollutant concentration, velocity, turbulence, and full video images of smoke visualized plumes.

The building orientation can have a significant effect on the maximum ground-level concentrations near a building. Slight angles were observed to result in the maximum being increased by a factor of 2-3 at x=3H. Concentrations were only increased by a factor of 1.5 at x=10H. The pattern of concentrations can be well explained by expected enhanced turbulence, vortex flow, and streamline convergence observed in previous studies.

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A LOOK AT THE INFLUENCE OF BUILDING ORIENTATION ON PLUME DISPERSION IN THE WAKE OF A BUILDING

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1. INTRODUCTION

The entrainment of plumes emitted from short stacks into the wake of a building can result in maximum ground-level concentrations that are significantly greater than those found for similar sources in the absence of the building influences. Both the oscillations of the wind flow and the enhanced turbulence in the near-wake of a building result in enhanced plume dispersion. For a ground-level source, the average ground-level concentrations are thus decreased. However, ground-level concentrations downwind of short stacks are increased since the plume is brought to the ground nearer the source. The entrained plume is less dilute than would naturally evolve under atmospheric dispersion processes. For both situations, ground-level concentrations in the far-wake converge to values that would occur in the absence of the building.

The pattern of wind flow over a building is influenced by the orientation of the building. An oblique orientation into the wind results in a greater deflection of streamlines toward the ground. The orientation of the building also alters the patterns of vortex flow and turbulence initiated in the wake of the building. This paper briefly reviews some observations of cross-stream profiles of pollutant concentrations in the near-wake of a building. The effect of building orientation is examined for the purpose of providing an improved understanding and application guidance for estimating pollutant concentrations from short stacks and accidental releases near a building.

Observations of mean pollutant concentration profiles downwind of a block-shaped model building are reported here. These data are part of a more comprehensive fluid model study of building wake effects conducted in the U. S. Environmental Protection Agency's Fluid Modeling Facility. The study includes point measurements of pollutant concentration, velocity, turbulence, and full video images of smoke visualized plumes. The analyses of the video images is providing a unique investigation of the transient nature of building-wake dispersion (Huber and Arya, 1985).

*On assignment from Department of Commerce, National Oceanic and Atmospheric Administration

2. EXPERIMENTAL PROCEDURE

Detailed features and operational characteristics of the environmental wind tunnel are described by Snyder (1979). A combination of a 15-cm fence followed by surface roughness elements was used to produce a 1-meter deep simulated atmospheric boundary layer. The rectangular block model building had both height (H) and along-wind depth (D) equal to 0.1 m. The cross-wind width (W) was fixed at either 0.2 m, 0.4 m or 0.8 m for these experiments. A hydrocarbon tracer was used to measure mean concentration profiles downwind from a source placed at the cross-wind building center along the leeward building edge. The neutrally buoyant ethane tracer gas was released through a hollow, perforated plastic 10 mm diameter ball. The plume from the source is without plume rise. The source height for these experiments was fixed either at ground level (HS=0) or at 1.5 times the building height (HS=1.5H).

For these experiments, the building was rotated counterclockwise around the source and fixed at either 0, 15, 30, 45, or 60 degrees. A few observations were also taken with the building rotated clockwise around the source and fixed at -15 or -30 degrees in order to verify the expected symmetry. For the W=2H building, the projected cross-wind building dimension (PW) ranges from 2H for 0 degrees rotation to 1.87H for 60 degrees rotation. Similarly, for the W=4H and W=8H buildings, PW ranges from 4H to 2.87H and 8H to 4.87H, respectively.

The mean concentration profiles represent steady-state average concentrations for a fixed wind direction. In absence of building effects, the plume dispersion can be considered as representative of atmospheric dispersion typical for Pasquill-Gifford stability categories C to D. A freestream mean wind speed (U) was fixed at 4.75 m/s for all experiments. In the absence of plume rise, the model wind speed affects only the plume dilution. The tracer emission (Q) was fixed for all experiments. The observed concentrations (χ) are presented in a non-dimensional form, $\chi UH^2/Q$. The building Reynolds Number (UH/ν) using the wind speed at building height was fixed at 25,000 for all experiments. Identical matching of the experimental Reynolds number to that for larger

field scales is not necessary provided that the often-quoted critical value of 11,000 is exceeded. The reported concentrations can be linearly rescaled to represent comparable fixed field situations. The discussion presented here relates solely to the different experiments, thus the concentration scaling is not important.

3. EXPERIMENTAL RESULTS

Figures 1 and 2 present lateral concentration profiles at distance x=3H downwind of the ground-level source (HS=0) and the elevated source (HS = 1.5H), respectively. Profiles were taken for each of seven fixed angles at ground level (z=0) and an elevated level (z=1.5H).

For the ground-level source (Figure 1a) an oblique orientation resulted in a factor of two increase in the ground-level maximum concentration. The smaller angles resulted in the greatest increase. The ground-level profiles for all angles have a comparable lateral spread. The patterns for the elevated profiles (Figure 1b) were observed to be quite different. The perpendicular orientation resulted in maximum concentrations twice larger than for the oblique orientations. The lateral plume spread for the oblique orientations were decreased and the peak concentrations were skewed in alignment with the side edge that has been rotated in the downwind direction. Apparently, as expected, the oblique orientation caused a significant deflection of the streamlines toward the ground and a lateral compression of the streamlines above the building.

For the elevated source (Figure 2a) the maximum ground-level concentrations were only slightly increased for the oblique orientations. The pattern of ground-level plume spread was slightly less than that observed for the ground level source. The pattern for the elevated profiles (Figure 2b) was quite different. The lateral plume spread was much narrower. The maximum concentrations for the perpendicular orientation was observed to be slightly higher than at ground level. The maximum concentrations for the oblique orientations were observed to decrease with increasing angle. Apparently, as expected, the oblique orientation resulted in a significant deflection of streamlines toward the ground. There may also have been some lateral compression of streamlines. However, the plume was not observed to be as strongly skewed in alignment with the building edge as was observed for the ground-level source.

A larger group of profiles were taken at downwind distance x = 10H. Profiles at this distance were far enough downwind of the building to be outside of the highly turbulent flow zone, but close enough to reflect the overall building influences. Figure 3 summarizes several key measures for five groups of profiles. Lines 1 and 2 are for profiles with the same building and sources reported by Figures 1 and 2, respectively. The other groups (lines 3,4 and 5) are for these same two sources but with a wider building. Comparisons among lines 1, 3, and 5 demonstrate the effect of increased building width for the ground-level source. Comparisons among lines 2 and 4 do the same for the elevated source.

Concentration maxima are summarized in Figure 3. They represent the plume-centerline concentrations. For both the ground-level source and the elevated source, the influence of angle orientation was similar to that observed at x=3H (Figures 1 and 2). However, for the elevated source, the maximum ground-level concentrations remained equal for angles equal to or greater than 30 degrees. Note that the relative differences in the magnitude among the maximum for both the ground-level source compared to the elevated source and the ground-level profile compared to the elevated profile were diminished due to added mixing during the increased time of travel. For both the ground-level source and the elevated source the ground-level profile maximum was decreased in proportion to the increased building width. The proportionality was somewhat less than the full scale change. For both sources, the elevated profile maximum was not affected by increased building width for angles less than or equal to 30 degrees. However, for 45 and 60 degree angles the maximum increased in proportion to the width increase. The lateral location of these maxima were in alignment with the building edge. The wider buildings, apparently had a higher vertical mixing depth downwind of the lateral edge.

Lateral dispersion parameters (sigma y) are summarized in Figure 3. They represent the calculated lateral plume standard deviation non-dimensionalized by the building height. For the W=2H building, sigma y was not significantly effected by angle. For the wider buildings, sigma y was greater, but was significntly reduced for angles greater than 30 degrees. These differences among all comparisons of sigma y appear to follow the pattern of change in the projected downwind dimension of the building. However, the proportionality was not exactly the same as the scale change. The differences in proportionality among comparisons for 0 degrees and comparisons for 60 degrees appear to demonstrate added lateral flow convergence for the larger angles. Sigma y was observed to be smaller for the elevated profiles for both sources. The sigma y for the elevated source was relatively smaller and less effected by angle in comparison to that for the ground-level source.

The integrated distribution of concentration profiles are summarized in Figure 3. The integrated profiles were calculated using equally non-dimensionalized concentrations and lateral scales. Comparisons among the integrated profile values represent differences in the total amount of measured pollutant across the profile. These are not total flux measurements since transport speeds were not incorporated into the calculations. The values for the integrated profiles nearly follow the pattern of concentration maxima. The only significant difference was for ground-level profiles for the ground-level source. Apparently, for these situations with large angles, there was increased vertical mixing and/or a plume uplift from the ground in order to explain the decreased values for the integrated lateral profiles.

4. CONCLUSIONS

The building orientation can have a significant effect on the maximum ground-level concentrations near a building. Slight angles were observed to result in the maximum being increased

by a factor of 2-3 at x = 3H. Concentrations were only increased by a factor of 1.5 at x=10H. The pattern of concentrations can be well explained by expected enhanced turbulence, vortex flow, and streamline convergence observed in previous studies.

LEGEND FOR FIG. 1 AND FIG. 2

SYMBOL	ANGLE
+	0
*	15
□	30
◇	45
△	60
×	-15
⊠	-30

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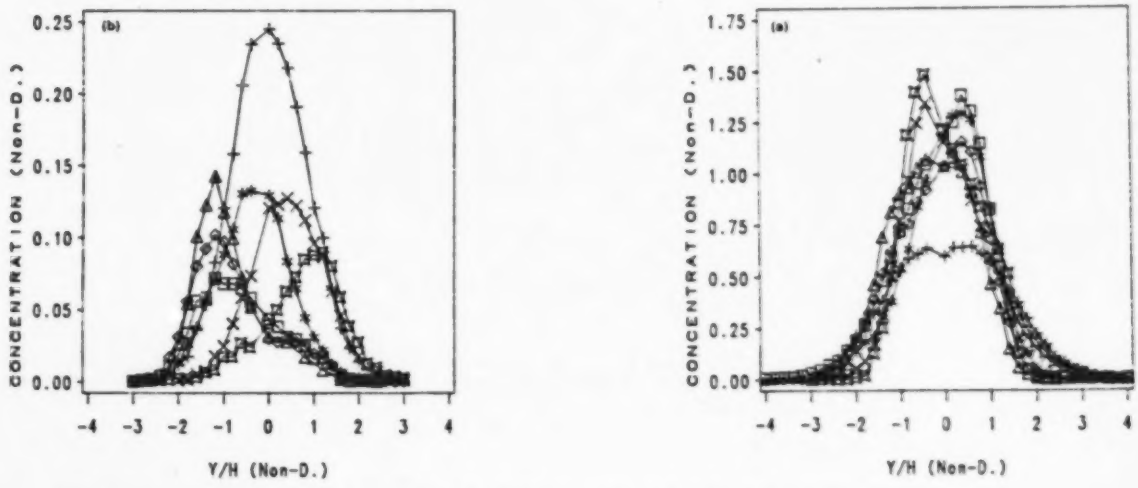

Fig. 1. Concentration profiles for HS=0, W=2H at x=3H: (a) z=0, (b) z=1.5H.

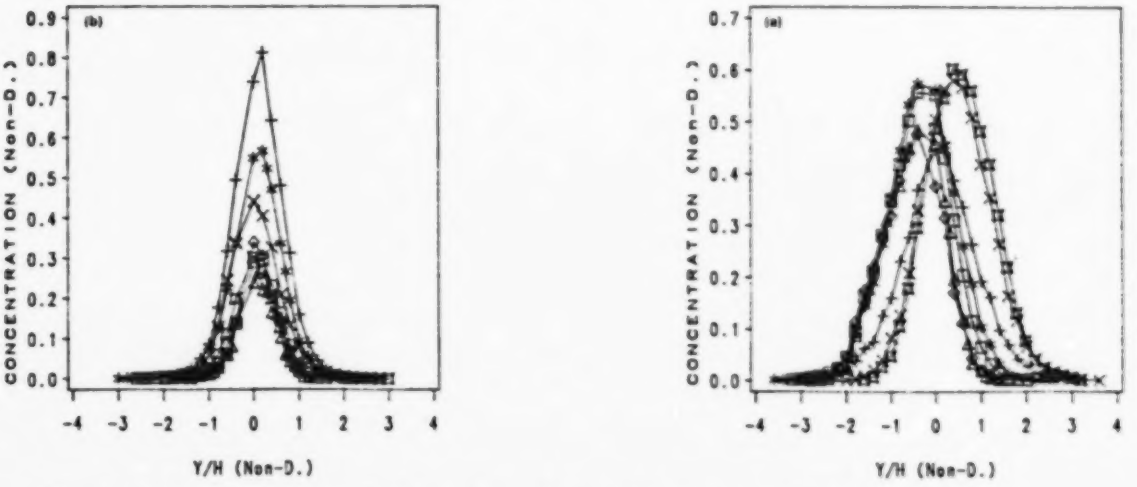

Fig. 2. Concentration profiles for HS=1.5H, W=2H at x=3H: (a) z=0, (b) z=1.5H.

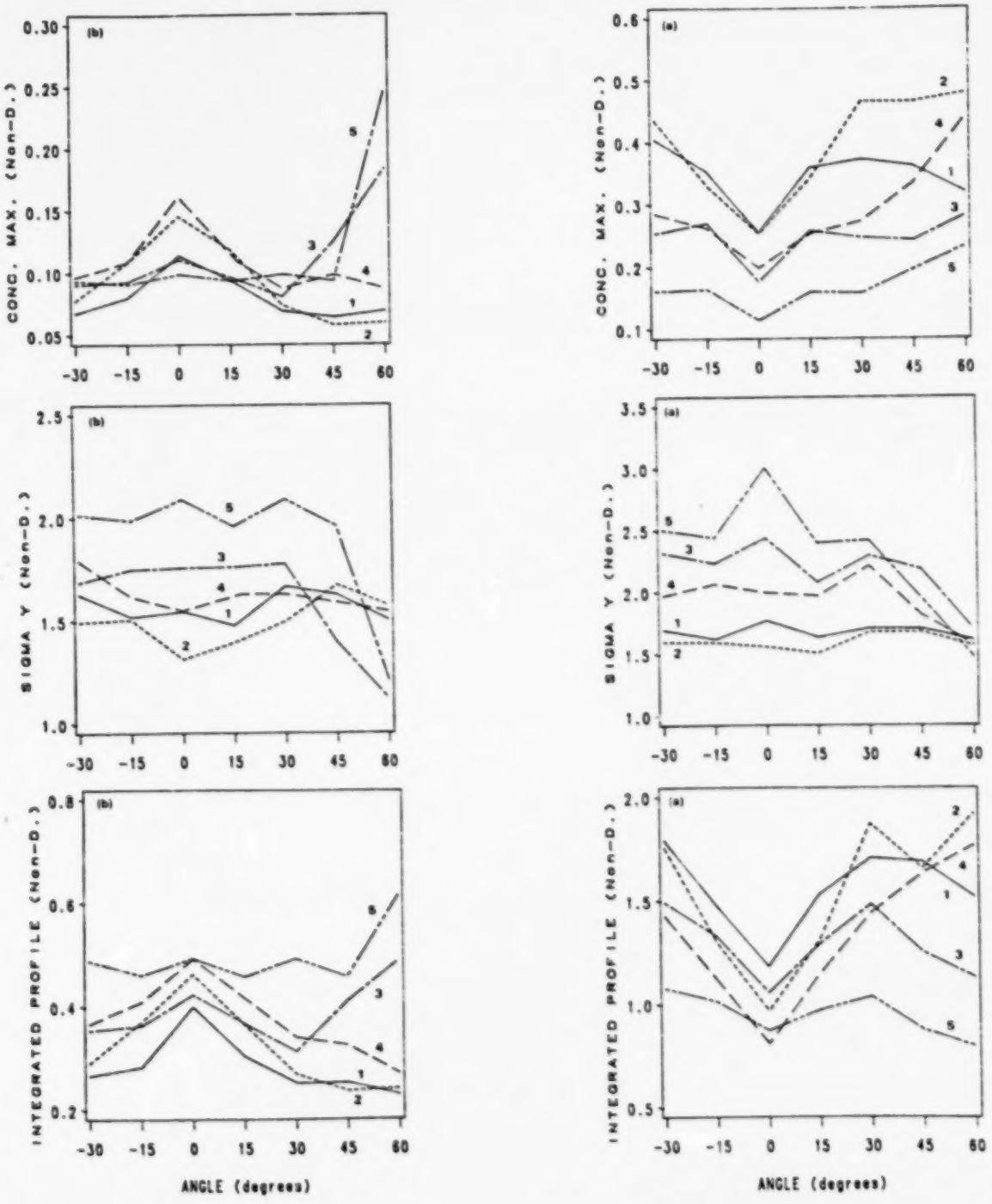

Fig. 3. Summary of concentration maxima, lateral dispersion parameters, and integrated profiles at x=10H: (a) z=0, (b) z=1.5H.

LINE	NO.	W/H	HS/H
———	1	2	0
———	2	2	1.5
———	3	4	0
- - - - -	4	4	1.5
———	5	8	0